An Investigation of the Seasonal Variation of Equatorial Electrodynamics and Scintillation using a Coupled Atmosphere-Ionosphere Model

Dr. Sarah McDonald
Space Science Division Code 7643
Naval Research Laboratory
Washington, DC 20375
phone: (202) 404-8555 fax: (202) 404-8090 email: sarah.mcdonald@nrl.navy.mil

Dr. Joseph Huba
Plasma Physics Division Code 6794
Naval Research Laboratory
Washington, DC 20375
phone: (202) 767-6863 fax: (202) 767-0631 email: joe.huba@nrl.navy.mil

Award Number: N0001409WX21358
http://www.nrl.navy.mil

LONG-TERM GOALS

The goal of this work is to determine the physical processes responsible for the observed seasonal patterns in the occurrence and intensity of scintillation in the Earth's low-latitude ionosphere. An improved understanding of the physics will result in more sophisticated modeling and forecasting tools that will benefit the Navy.

OBJECTIVES

The objective of this study is to couple a three-dimensional physics based model of the ionosphere (SAMI3) with a global circulation model (TIME-GCM) and a tidal and planetary wave model (GSWM) in order to investigate lower atmospheric influences on the seasonal and longitudinal variability in the occurrence of scintillation. During the first two years, we will also use the SAMI3/ESF "wedge" model to gain insight into how the instabilities are quenched. In the third year, studies will be conducted with the ESF portion fully coupled into SAMI3.

APPROACH

The SAMI3 interface will be modified as necessary to accommodate the output from the NCAR TIME-GCM. Simulations with the coupled model will be conducted to determine the effects of the lower atmosphere on the ionosphere. The "background" ionosphere generated from these simulations will be used in the SAMI3/ESF model to explore the conditions under which scintillation occurs.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **An Investigation Of The Seasonal Variation Of Equatorial Electrodynamics And Scintillation Using A Coupled Atmosphere-Ionosphere Model**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,Space Science Division Code 7643,Washington,DC,20375**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The goal of this work is to determine the physical processes responsible for the observed seasonal patterns in the occurrence and intensity of scintillation in the Earth?s low-latitude ionosphere. An improved understanding of the physics will result in more sophisticated modeling and forecasting tools that will benefit the Navy.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

WORK COMPLETED

In FY09, we have completed a one-way coupling of the NRL SAMI3 ionosphere model [*Huba et al*., 2000] and the NCAR Thermosphere-Ionosphere-Mesosphere-Electrodynamics General Circulation Model (TIME-GCM). Figure 1 shows the models used in the study and how they are coupled. The Global-Scale Wave Model (GSWM) [*Hagan et al.*, 1995] is a numerical model of planetary waves and solar tides in the Earth's atmosphere. In order to capture the effects of tropospheric tides in TIME-GCM, the lower boundary at 30 mb (approximately 10 km) is perturbed with the GSWM winds and temperatures. TIME-GCM simulations are performed at NCAR and provide the neutral densities (O, N_2, O_2, N, H, and NO), temperature and winds from 10 to 500 km that are fed into SAMI3. The one-hourly data provided by TIME-GCM is interpolated to 15-minute intervals. Neutrals above 500 km are assumed to be constant with altitude. Because TIME-GCM does not solve for Helium, this constituent is provided by NRLMSISE-00 [*Picone et al*. 2002]. The version of SAMI3 we are using includes a potential solver to self-consistently solve for the electric fields. The magnetic field is specified by a tilted dipole, though it will be replaced by a more realistic magnetic field model in the near future.

Figure 1. Models used in the simulations. The arrows indicate the one-way coupling between models.

To test the model, we performed two sets of simulations, one for equinox conditions and the other for June solstice conditions, both at solar minimum (F10.7 = 75). For each set, we used two different boundary conditions set by GSWM. In one case, both migrating and non-migrating tides were included and in the other case, the non-migrating tides were suppressed. By performing the SAMI3 simulations with both cases, we are able to determine the effects of non-migrating tides on the ionosphere.

RESULTS

We have successfully coupled the thermospheric component of TIME-GCM and GSWM to SAMI3 in order to investigate the impact of lower atmospheric tides on the electrodynamics and electron content of the low-latitude ionosphere. This is the first step toward understanding the role the lower atmosphere plays in the climatology of scintillation in that we can now simulate the background ionosphere in which smaller scale irregularities form.

Figure 2 shows the SAMI3 simulation results at a constant local time for each of the cases discussed above. A comparison of Figure 2a and 2b shows the effects non-migrating tides have on the ionospheric total electron content (TEC) at 1600 LT under solar minimum conditions (F10.7 = 75) at March equinox. Figure 2c shows that the pattern persists into the evening hours. The four-peaked longitudinal structure is qualitatively similar to ionospheric ultraviolet emissions measured by

IMAGE-FUV [*Immel et al*., 2006]. Figures 2d -2f show that the longitudinal pattern is also present at June solstice, especially in the northern equatorial ionization anomaly crest (enhanced TEC region roughly 15° north of the magnetic equator). By varying the thermospheric input into SAMI3, we have found that the zonal neutral wind modulated by the non-migrating tides is the primary driver of this four-peaked longitudinal pattern, as opposed to the longitudinal variations in the neutral densities and temperature. This is an expected result because the E-region neutral winds (~120 km) drive the electric fields that cause the F-region (above 250 km) to $\mathbf{E} \times \mathbf{B}$ drift upward and form the equatorial ionization anomaly (EIA). Figure 3 shows the difference between the TIME-GCM winds with and without the non-migrating tidal component. The four-peaked pattern is present in the zonal and meridional winds in both seasons and is particularly strong in the lower thermosphere (100 to 150 km).

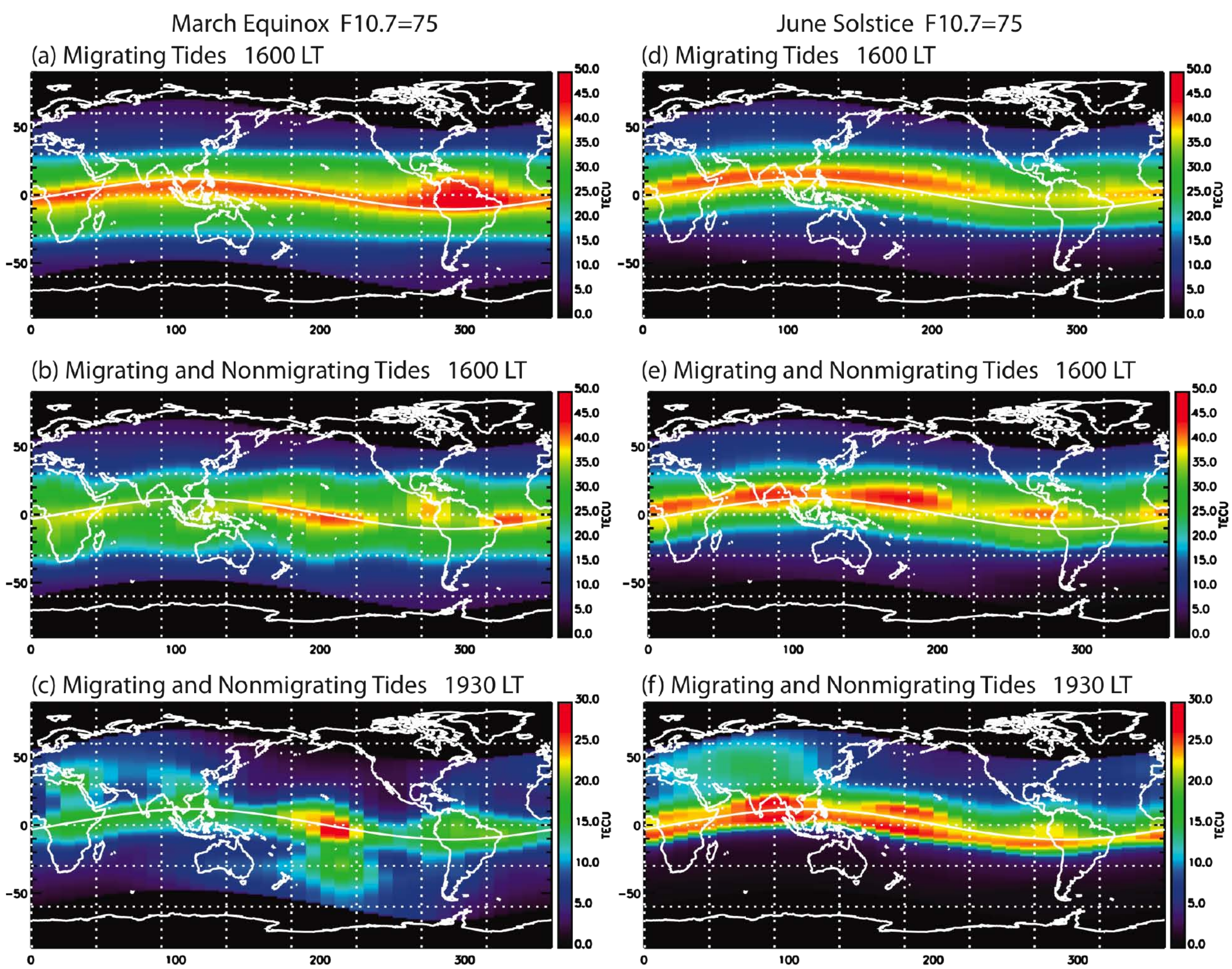

Figure 2. SAMI3 total electron content (TEC) for March equinox at solar minimum (a – c) and June solstice (d – f). (a) TEC at 1600 LT during March equinox where non-migrating tides have been suppressed (b) TEC at 1600 LT during March equinox where the non-migrating tides are included. The non-migrating tides have a significant impact on the longitudinal structure of the EIA. (c) TEC at 1930 LT during March equinox where migrating and non-migrating tides are included. (d) TEC at 1600 LT.

A comparison between the two seasons shows that the March winds are approximately four times stronger than the June winds, but the four-peaked structure in TEC appears to be stronger in June than March, especially in the evening hours (Figures 2c and 2f). The suspected reason for this difference is due to the meridional winds. Strong F-region meridional winds (~ 300 km) strongly affect the densities in the EIA crests by pushing the plasma up or down the field lines into regions of slower or faster recombination of electrons with oxygen ions. Further modeling studies and especially comparisons with measurements of winds and electron densities will be necessary in order to determine the true contribution of the meridional winds to the observed longitudinal pattern. Preliminary comparisons with wind data suggest that the lower thermospheric winds from TIME-GCM at March equinox may be too large.

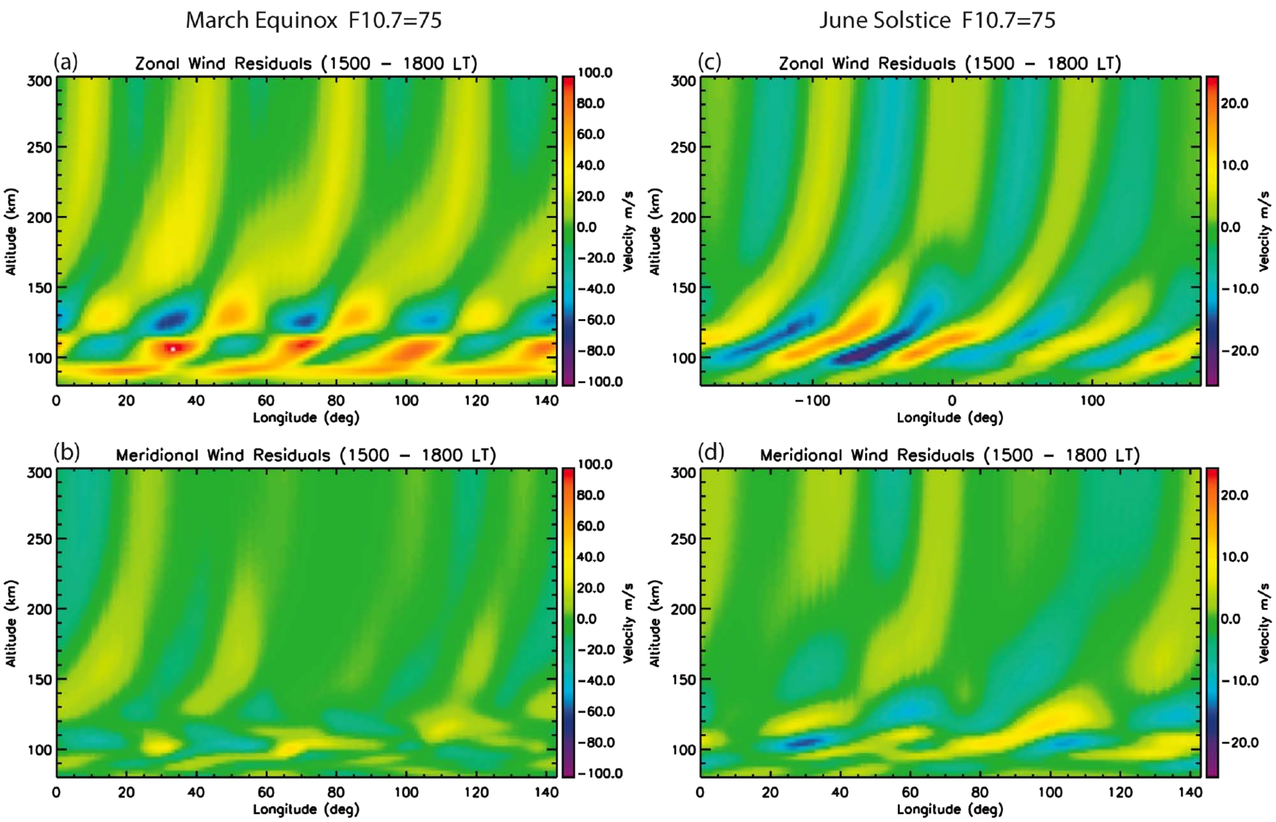

Figure 3. These figures show the difference between the TIME-GCM thermospheric winds with and without non-migrating tidal effects. The winds are averaged over four hours and shown in constant local time as a function of longitude and altitude. The zonal winds in the E-region ionosphere (90 – 140 km) are responsible for the four-cell pattern in the TEC shown in Figure 2. The F-region meridional winds (above 250 km) also have an effect on the TEC in the EIA crests, especially in the March equinox case. Figures (a) and (b) are the zonal and meridional wind residuals for the March equinox conditions, and Figures (c) and (d) are the winds for the June solstice conditions. Note that the TIME-GCM March winds are roughly four times stronger than the June winds.

IMPACT/APPLICATIONS

The purpose of this work is to determine the impact lower atmospheric tides have on the seasonal and longitudinal patterns in the occurrence of scintillation. The understanding gained through this research will be used to improve forecasting models of low-latitude ionospheric disturbances that cause scintillation in radio communication signals. Additionally, an improved 3D physics-based model of the ionosphere (SAMI3/ESF), including small-scale disturbances, will also result from this research.

RELATED PROJECTS

The following projects have been funded to support the development of the SAMI3/ESF code that is being used in our study.

1. NRL ARI:

Title: Equatorial spread F: Specification and forecasting
The purpose of this 6.1 effort is to develop the first, first-principles, global model of equatorial spread F, and an observational database to provide driver inputs and data for comparative studies.

2. NASA Living With a Star Grant

Title: Modeling Large Scale Electron Density Gradients in the Low- to Mid-Latitude Ionosphere
This is a three-year program to develop a comprehensive modeling capability to understand the onset and evolution of large-scale electron density structures in the low- to mid-latitude ionosphere.

3. NASA Living With a Star Grant

Title: Modeling of Tropospheric-Ionospheric Interaction
In this work, solar-driven and tidal winds will be integrated with the NRL SAMI model to self-consistently reproduce the dynamo electric fields that produce the equatorial ionization anomaly.

REFERENCES

Hagan, M.E., J.M. Forbes, and F. Vial, On modeling migrating solar tides, Geophys. Res. Lett. 22, 893, 1995.

Huba, J. D., G. Joyce, and J.A. Fedder, SAMI2 (Sami2 is Another Model of the Ionosphere): A new low-latitude ionosphere model, *J. Geophys. Res., 105*(A10), 23035-23053, 2000.

Immel, T.J., E. Sagawa, S.L. England, S.B. Henderson, M.E. Hagan, S.B. Mende, H.U. Frey, C.M. Swenson, and L.J. Paxton, Control of equatorial ionospheric morphology by atmospheric tides, *Geophys. Res. Lett., 33*, L15108, doi:10.1029/2006GL026161, 2006.

Picone, J. M., A. E. Hedin, D. P. Drob, and A. C. Aikin, NRLMSISE-00 empirical model of the atmosphere: Statistical comparisons and scientific issues, *J. Geophys Res., 107*, doi:10.1029/2002JA009430, 2002.

PUBLICATIONS

Basu, Su., S. Basu, J.D. Huba, J. Krall, S.E. McDonald, J.J. Makela, E.S. Miller, S. Ray, and K. Groves, Day-to-day variability of the equatorial ionization anomaly and scintillations at dusk observed by GUVI and modeling by SAMI3, J. Geophys. Res. 114, A04302, doi:10.1029/2008JA013899, 2009. [published]

Huba, J.D., G. Joyce, J. Krall, and J. Fedder, Ion and electron temperature evolution during equatorial spread F, Geophys. Res. Lett. 36, L15102, doi:10.1029/2009GL038872, 2009. [published]

Huba, J.D., J. Krall, and G. Joyce, Atomic and molecular ion dynamics during equatorial spread F, Geophy. Res. Lett. 36, L10106, doi:10.1029/2009GL037675, 2009. [published]

Hysell, D.L., J.L. Chau, and J.D. Huba, Topside measurements at Jicamarca during solar minimum, Ann. Geophys. 27, 427, 2009. [published]

Krall, J., J.D. Huba, G. Joyce, S. Zalesak, Three-dimensional simulation of equatorial spread-F with meridional wind effects, Ann. Geophys. 27, 1821, 2009. [published]

Krall, J., J.D. Huba, and C.R. Martinis, Three-dimensional modeling of equatorial spread F airglow enhancements, Geophys. Res. Lett. 36, L10103, doi:10.1029/2009GL038441, 2009. [published]

Maruyama,T., S. Saito, M. Kawamura, K. Nozaki, J. Krall, and J. D. Huba, Equinoctial asymmetry of a low-latitude ionosphere-thermosphere system and equatorial irregularities: evidence for meridional wind control, Ann. Geophys. 27, 2027, 2009. [published]

Meier, R.R., C. Englert, D. Chua, D. Socker, J. M. Picone, T. Carter, J. Huba, S. Slinker, J. Krall, and W. Vincent, Geospace imaging using Thomson scattering, J. Atmos. Sol. Terr. Phys. 71, 132, 2009. [published]

Huba, J.D., S.L. Ossakow, G. Joyce, J. Krall, and S.L. England, Three-dimensional equatorial spread F modeling: Zonal neutral wind effects, Geophys. Res. Lett., doi:10.1029/2009GL040284, 2009. [in press]

Krall, J., J.D. Huba, G. Joyce, and T. Yokoyama, Density enhancements associated with equatorial spread F, Ann. Geophys., 2009.

Huba, J.D., G. Joyce, J. Krall, C.L. Siefring, and P.A. Bernhardt, Self-consistent modeling of equatorial dawn density depletions with SAMI3, Geophys. Res. Lett., 2009.

McDonald, S.E., C. Coker, K.F. Dymond, D.N. Anderson, and E.A. Araujo-Pradere, The relative effects of daytime and evening vertical ExB drifts on the nighttime equatorial ionization anomaly, *J. Geophys. Res*., 2009.

HONORS/AWARDS/PRIZES

Dr. Joseph Huba, Naval Research Laboratory, E.O. Hulburt Annual Science Award (2009), sponsored by the Naval Research Laboratory.